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Sweeney et al.

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(54) **THREE DIMENSIONAL PRINTER APPARATUS**

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H05B 6/14	(2006.01)
B33Y 30/00	(2015.01)

(52) **U.S. Cl.**
CPC ***B29C 64/209*** (2017.08); ***H05B 6/14*** (2013.01); *B33Y 30/00* (2014.12)

(58) **Field of Classification Search**
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(Continued)

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(57) **ABSTRACT**

A three-dimensional printing apparatus for manufacturing a three-dimensional object includes a controller and a three-dimensional printer. The controller has a signal generator. The three-dimensional printer includes a print head, a part carrier, and a plasma field applicator. The plasma field applicator is disposed on an end of the print head. The controller is in communication with the print head, part carrier, and plasma field applicator. The three dimensional printer builds the three-dimensional object onto the part
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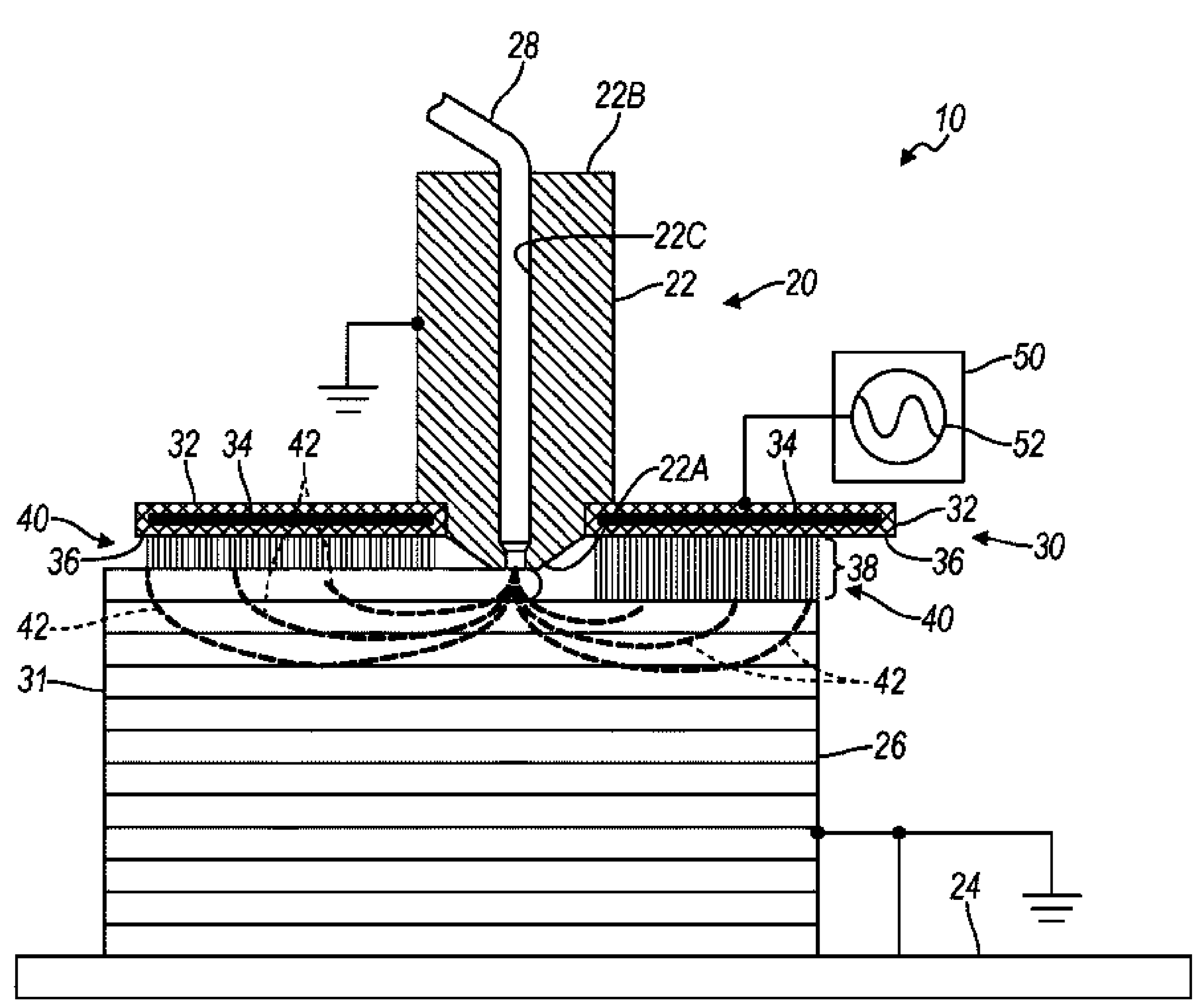

carrier. The signal generator outputs a signal to the plasma field applicator and the plasma field applicator generates an electromagnetic field and induced current pathway incident to the three-dimensional object on the part carrier.

17 Claims, 6 Drawing Sheets

(58) **Field of Classification Search**
CPC B33Y 10/00; B33Y 40/00; B23K 10/027; B23K 10/02; H05B 6/14
See application file for complete search history.

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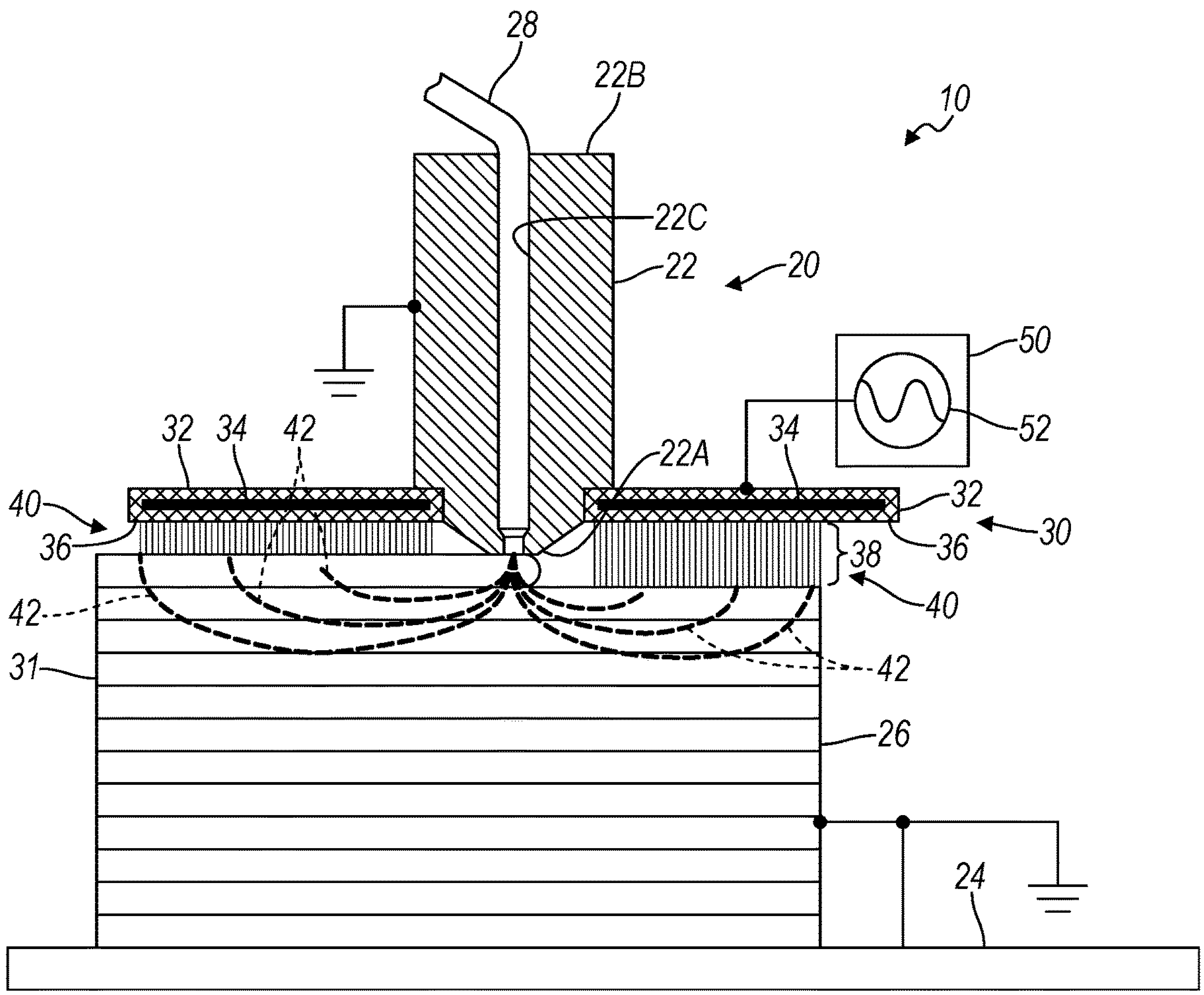
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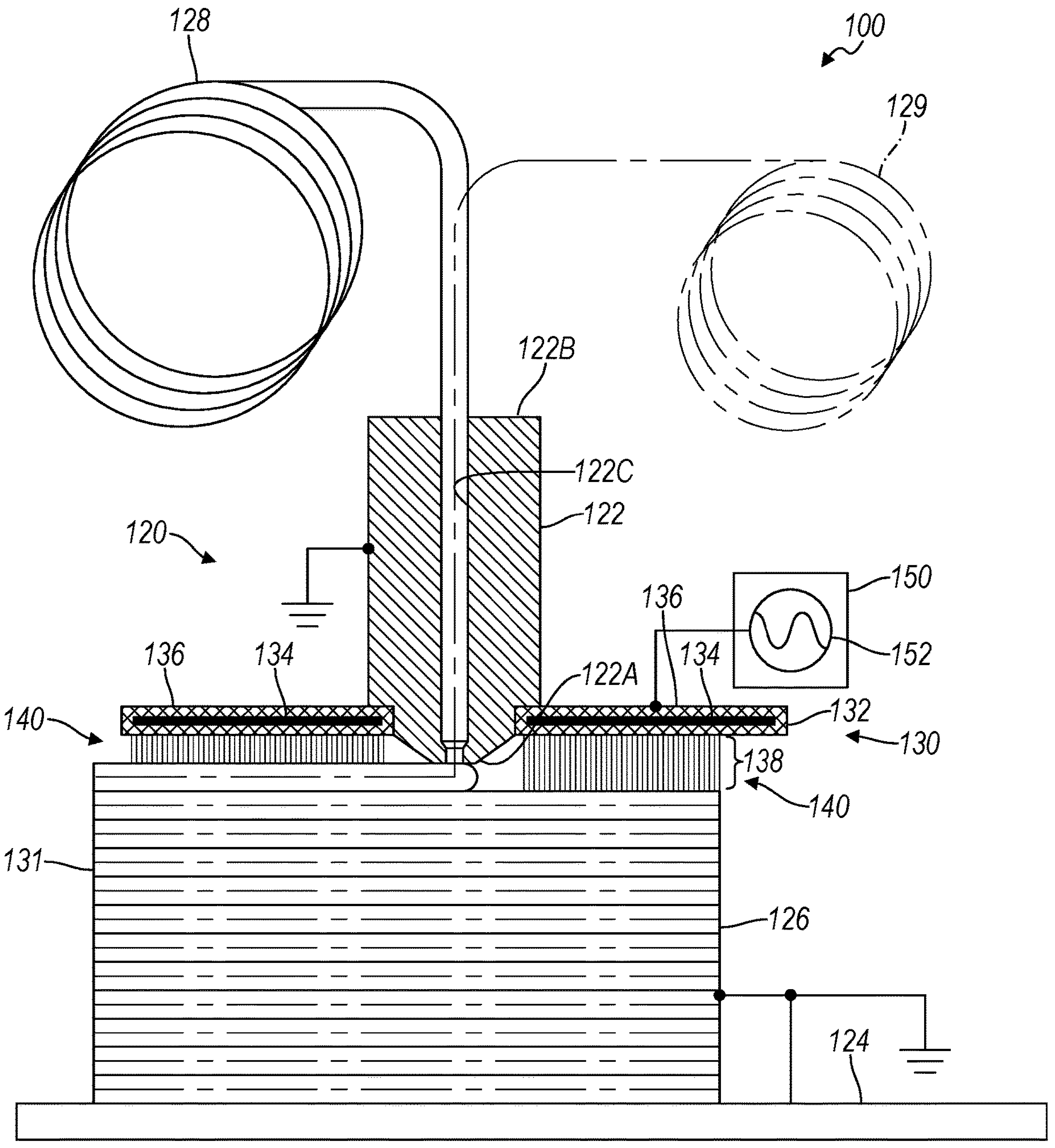
24

FIG. 1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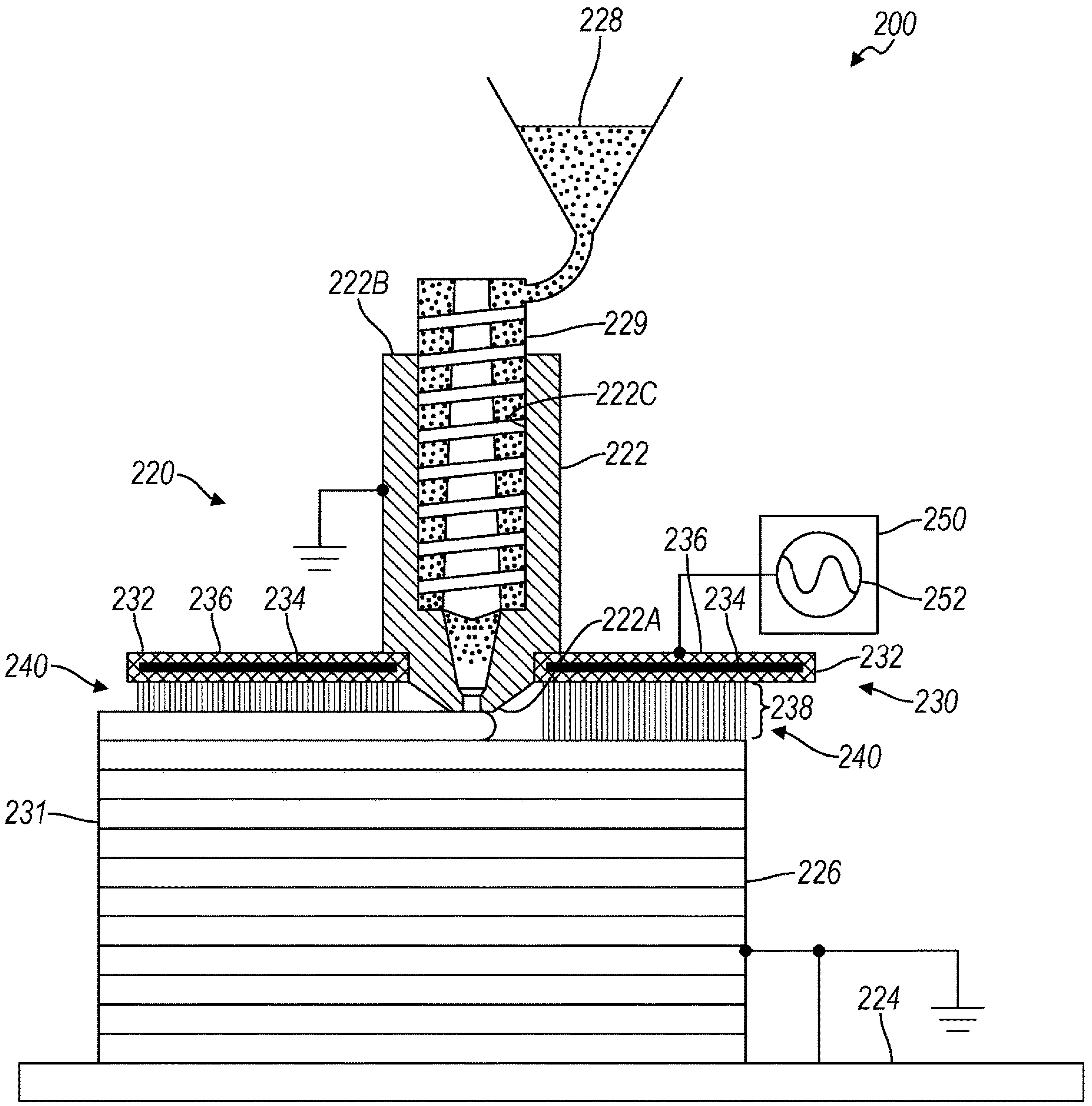
124

FIG. 2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200
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222C
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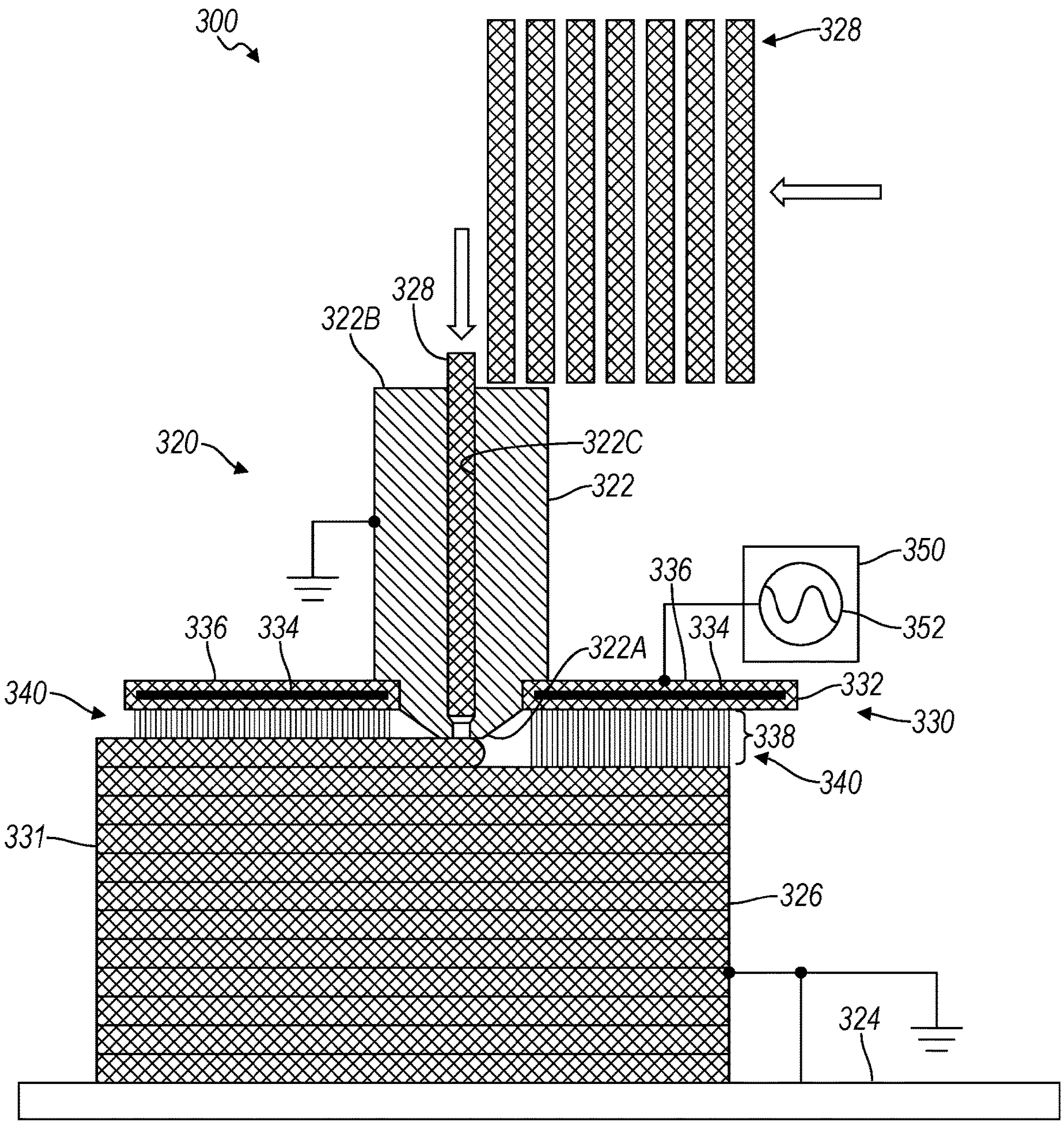
238
240
231
226
224

FIG. 3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328
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322B
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322C
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326
324

FIG. 4

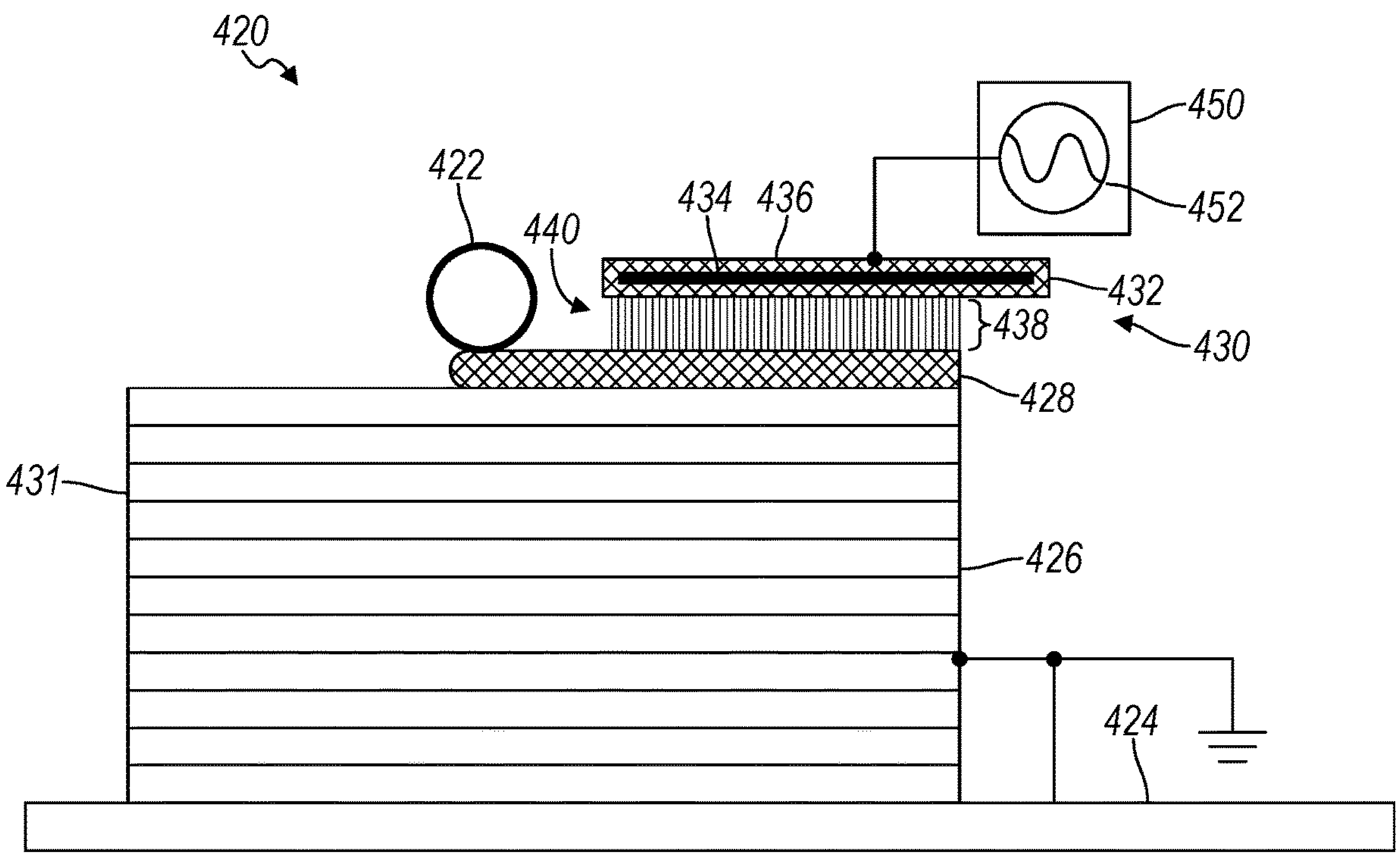

FIG. 5

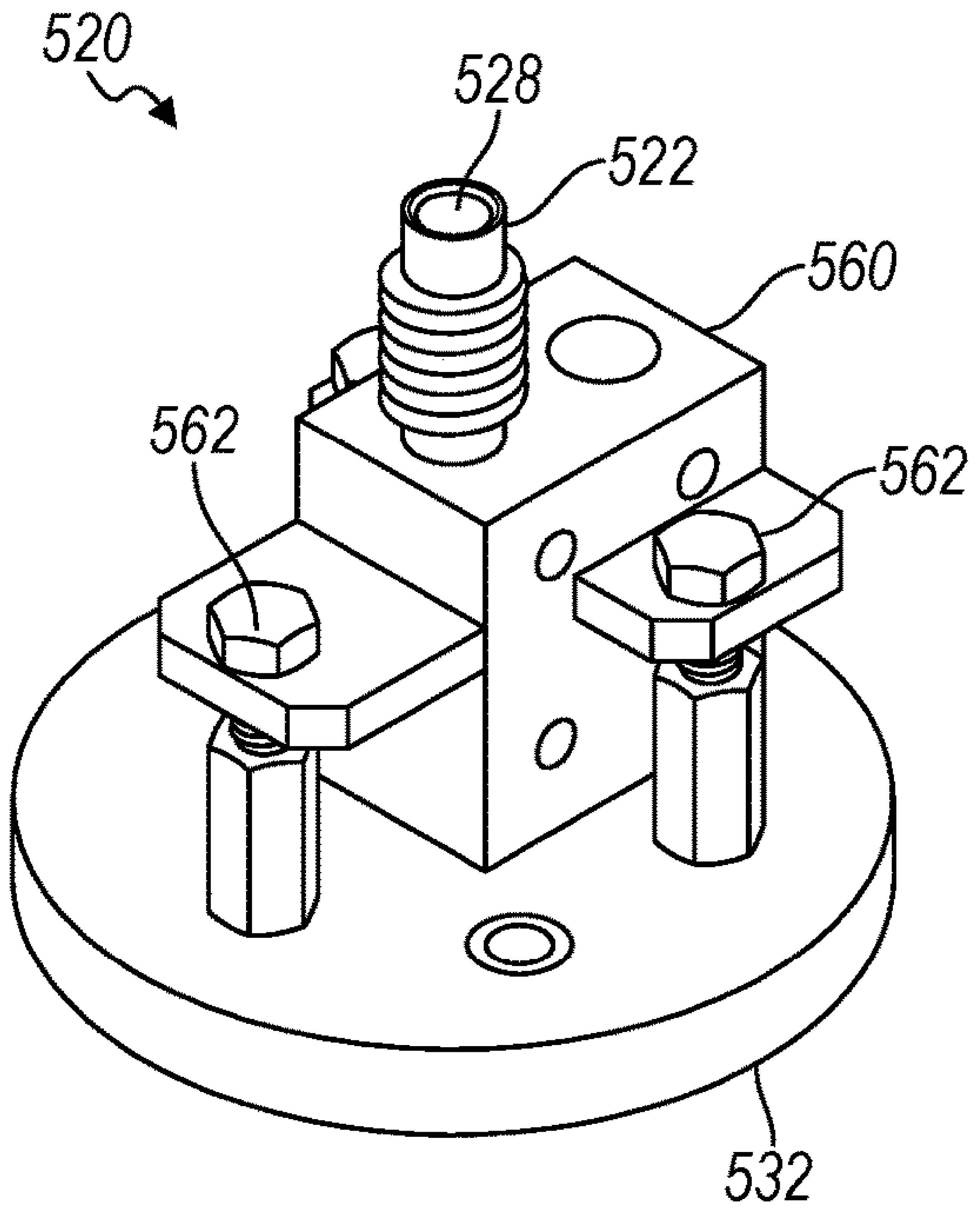

FIG. 6

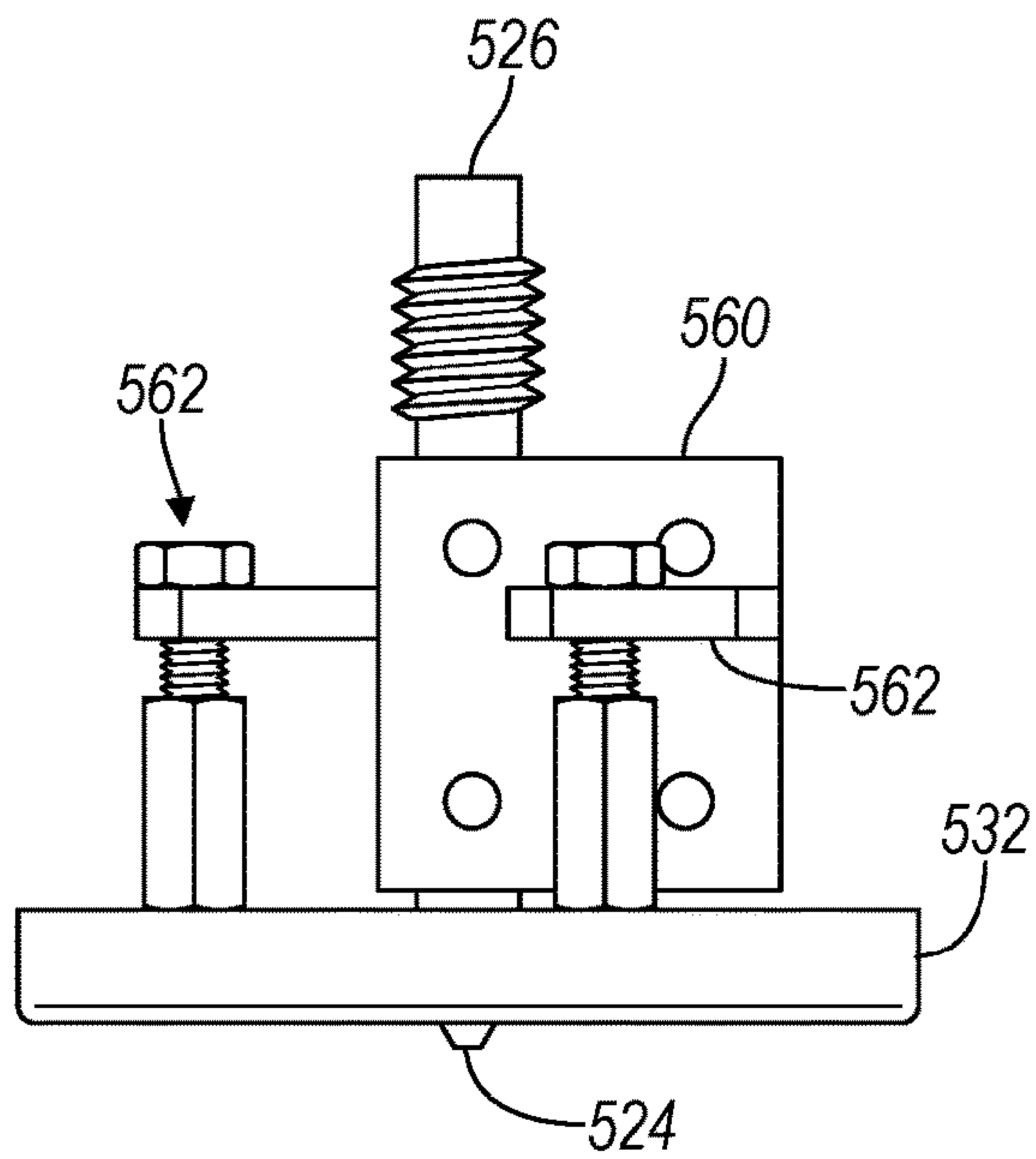

FIG. 7

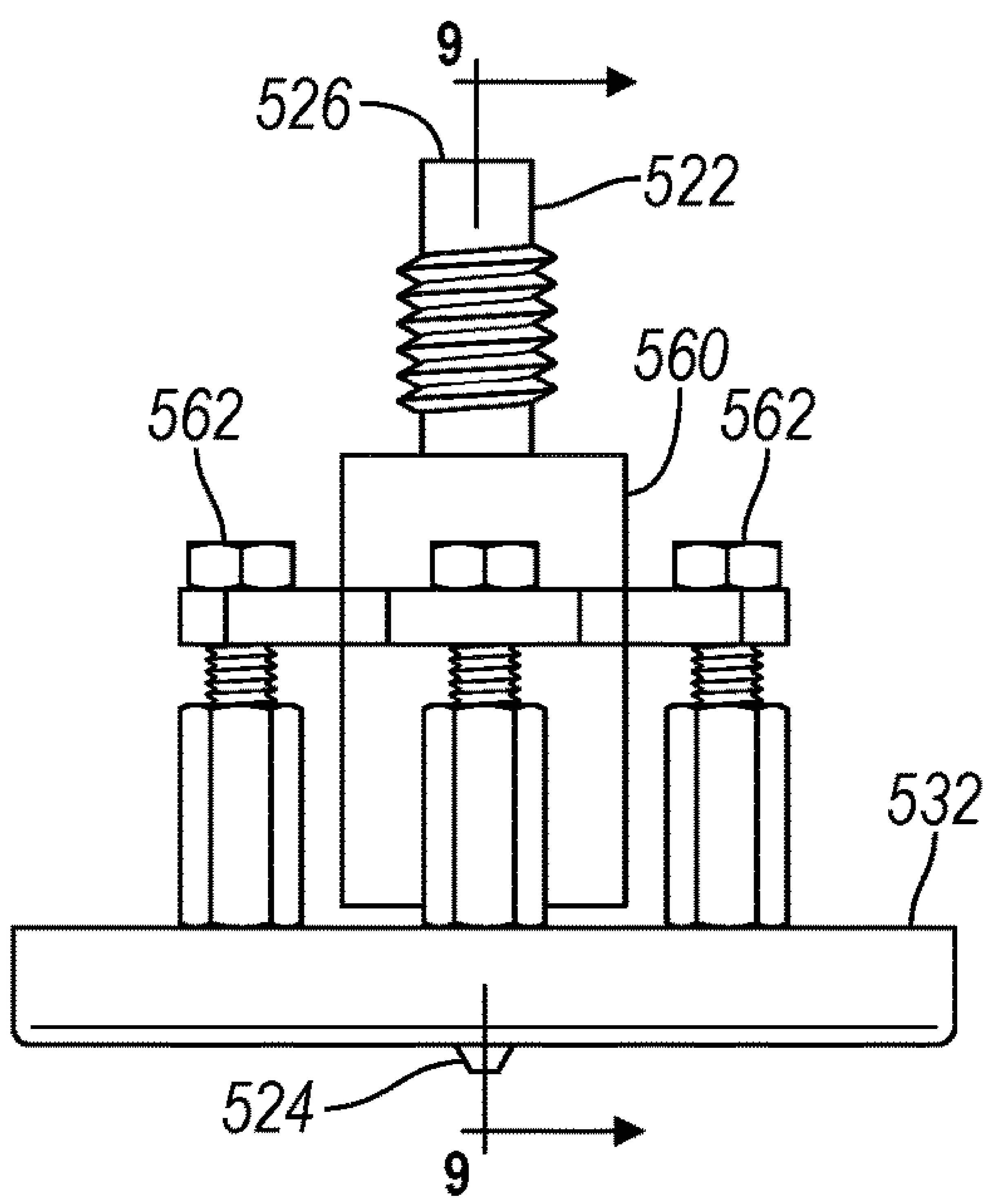

FIG. 8

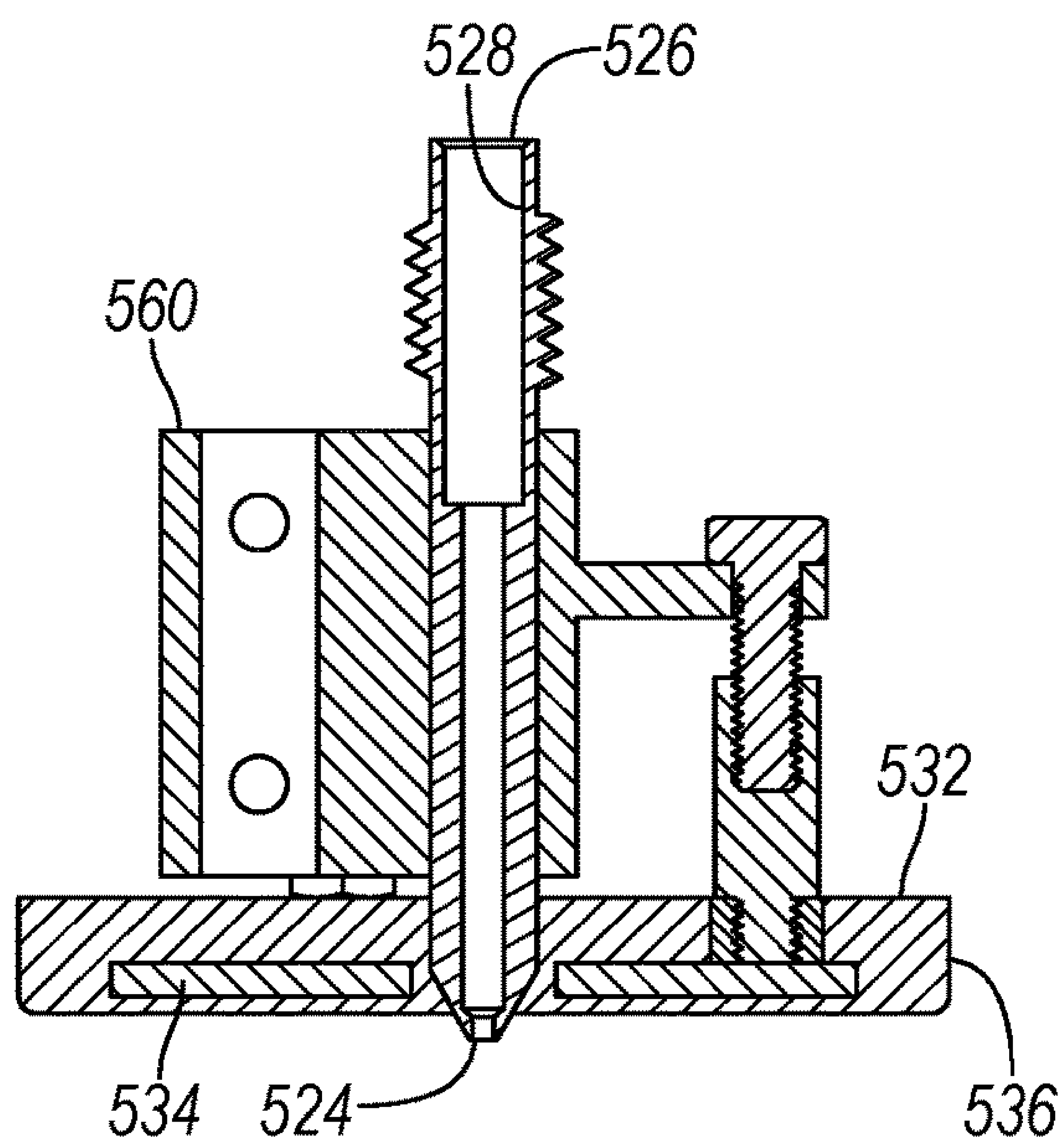

FIG. 9

THREE DIMENSIONAL PRINTER APPARATUS

This application is a national stage completion of international application number PCT/US2018/033409, filed on May 18, 2018, which claims the benefit of the U.S. Provisional Application No. 62/508,464 filed May 19, 2017, the entire disclosures of which are hereby incorporated herein by reference.

FIELD

The invention relates to an apparatus and methods for producing three dimensional printed parts.

BACKGROUND

The statements in this section merely provide background information related to the present disclosure and may or may not constitute prior art.

Three Dimensional Printing or Additive Manufacturing represents several processes for creating three dimensional objects from a digital CAD design model. A three dimensional printed part is formed by stacking several two dimensional layers of material such that the end result is an object having length, width, and height. In several of the processes, materials used to form the objects can range from metal to thermoplastic and composite. However, while these processes are capable of quickly producing intricate parts including great detail, the current processes seem capable of producing objects having only very limited purposes. Such purposes include prototype parts, novelty objects, demonstration parts or assemblies, or parts having other light duty purposes. This limited use is mainly due to the ability of the additive assembly processes to produce parts having high cohesive strength between several two dimensional layers of the printed part.

Some process improvements include attempts to increase the cohesive strength between the layers of the three dimensional printed object. These attempts include in-process and post-process steps that involve different methods of heating the printed object such that the layers soften or even melt to promote cross-solidification or crystallization between the layers. However, heating the entire three dimensional part either in-process or post-process may result in distortion of the part through sagging and lingering residual stresses, among other defects.

While current three dimensional printers and processes achieve their intended purpose, there is a need for an improved three dimensional printer and process for providing parts for an increasing array of applications requiring improved strength, dimensional capability, and multi-functional purposes.

SUMMARY

The present disclosure includes a three-dimensional printing apparatus for manufacturing a three-dimensional object comprises a controller and a three-dimensional printer. The controller has a signal generator. The three-dimensional printer includes a print head, a part carrier, and a plasma field applicator. The plasma field applicator is disposed on an end of the print head. The controller is in communication with the print head, part carrier, and plasma field applicator. The three dimensional printer builds the three-dimensional object onto the part carrier. The signal generator outputs a signal to the plasma field applicator and the plasma field applicator generates an electromagnetic field and induced current pathway incident to the three-dimensional object on the part carrier.

In one example of the present invention, the signal output to the plasma field applicator comprises a high potential electromagnetic signal.

In another example of the present invention, the high potential electromagnetic signal comprises an alternating current signal having a frequency between approximately 10 kHz and 100 kHz.

In yet another example of the present invention, the high potential electromagnetic signal comprises one of a continuous wave signal, a square wave signal, a triangle wave signal, a short duration pulse signal, and a rectified signal.

In yet another example of the present invention, the plasma field applicator comprises a high voltage electrode and a dielectric insulator and the high voltage electrode encapsulated by the dielectric insulator.

In yet another example of the present invention, the high voltage electrode of the plasma field applicator is connected to the signal generator and the part carrier is grounded.

In yet another example of the present invention, the plasma field applicator has a disc-like shape.

In yet another example of the present invention, the print head is a pass through continuous feed stock print head nozzle.

In yet another example of the present invention, the print head is a screw-type extrusion print head nozzle.

In yet another example of the present invention, the print head includes a powder compaction roller.

The above features and advantages and other features and advantages of the present disclosure are readily apparent from the following detailed description when taken in connection with the accompanying drawings.

DRAWINGS

The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

FIG. **1** depicts a three dimensional printing apparatus for executing a three dimensional printing process according to the principles of the present invention;

FIG. **2** depicts a three dimensional printing apparatus for executing a three dimensional printing process according to the principles of the present invention;

FIG. **3** depicts a three dimensional printing apparatus for executing a three dimensional printing process according to the principles of the present invention;

FIG. **4** depicts a three dimensional printing apparatus for executing a three dimensional printing process according to the principles of the present invention;

FIG. **5** depicts a three dimensional printing apparatus for executing a three dimensional printing process according to the principles of the present invention;

FIG. **6** is a perspective view of a printing head for a three dimensional printing apparatus according to the principles of the present invention;

FIG. **7** is a side view of a printing head for a three dimensional printing apparatus according to the principles of the present invention;

FIG. **8** is a front view of a printing head for a three dimensional printing apparatus according to the principles of the present invention, and

FIG. 9 is a cross-sectional view of a printing head for a three dimensional printing apparatus according to the principles of the present invention.

DETAILED DESCRIPTION

The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

Referring to FIG. **1**, a cross-section schematic of a three dimensional printing apparatus **10** is illustrated and will now be described. The three dimensional printing apparatus **10** includes a three dimensional printer **20**, a plasma applicator apparatus **30**, a controller **50**, and an excitation signal. More particularly, the three dimensional printer **20** includes a print head nozzle **22**, a part carrier **24**, and a supporting structure such as a Cartesian gantry (not shown), a delta-style structure or a robotic arm (not shown) that supports the print head nozzle **22**. The print head nozzle **22** is a pass through continuous feed stock print head nozzle **22** including a first end or nozzle tip **22**A, a second end or feed end **22**B, and a feedstock bore **22**C. The print head nozzle **22** is vertically disposed in a housing (not shown).

A three dimensional part **26** is initiated and built upon the part carrier **24** as a filament **28** passes through the print head nozzle **22** and is deposited on the part carrier **24** or a previous layer **31** of the three dimensional part **26**. One of or both the print head nozzle **22** and the part carrier **24** are capable of movement in the x, y, and z directions, or a combination of these directions composing circular or curved patters, for depositing the heated filament onto the previous layers **31** of the three dimensional part **26**.

The plasma applicator apparatus **30** includes a plasma field applicator **32** and the part carrier **24**. More particularly, the plasma field applicator **32** includes a high voltage electrode **34** encapsulated by a dielectric insulator **36**. The plasma field applicator **32** is disc-shaped and disposed on the nozzle tip **22**A of the print head nozzle **22** coaxially with the print head nozzle **22**. The part carrier **24** grounds the three dimensional part **26** to complete a conduction pathway that includes the plasma field applicator **32**, an air gap **38** between the three dimensional part **26** and the plasma field applicator **32**, the grounded three dimensional part **26**, and the part carrier **24**. The printer nozzle **22** is also grounded. As layers of the three dimensional part **26** are fully or at least partially completed, the plasma field applicator **32** moves over the three dimensional part **26** or moves in sufficiently close proximity to the three dimensional part **26** placing the three dimensional part **26** under or incident with a plasma field **40** created by the plasma field applicator **32**. The plasma field **40** completes the conduction pathway to directly couple the high voltage electrode **34** with the three dimensional part **26**. An electromagnetic field and induced current pathway **42** is, in addition to the plasma field **40**, produced by the plasma field applicator **32**. The plasma field **40** conductively couples the high voltage electrode **34** to the three dimensional part **26** creating the electromagnetic field and induced current pathway **42** as shown emanating from the face of the plasma field applicator **32** traveling to the nozzle tip **22**A of the print head nozzle **22**.

The controller **50** is preferably an electronic control device having a preprogrammed digital computer or processor, control logic, memory used to store data, and at least one I/O peripheral. The control logic includes a plurality of logic routines for monitoring, manipulating, and generating data. The controller **50** controls the operation the three dimensional printer **20** and the plasma applicator apparatus **30**. The control logic may be implemented in hardware, software, or a combination of hardware and software. For example, control logic may be in the form of program code that is stored on the electronic memory storage and executable by the processor. The controller **50** provides control signals, generated by special software that creates pathways for the nozzle based on specific cross-section geometry that comes from a CAD model data program, to the gantry, the print head nozzle **22**, the plasma field applicator **32**, and the part carrier **24** thus producing the three dimensional part **26**. The controller may also modify the frequency, voltage, current, and waveform shape of the plasma.

A further feature of the controller **50** is a signal generator **52** that outputs a high potential electromagnetic signal to the plasma field applicator **32**. The signal generator **52** preferably provides an alternating current signal between 10-100 kHz to eliminate radiation and maximize conduction heating efficiency. However, any signal frequency or waveform shape may be used, including but not limited to continuous waves, square waves, triangle waves, short duration pulses, and rectified signals.

Referring now to FIG. **2**, another example of a three dimensional printing apparatus **100** is illustrated and will now be described. The three dimensional printing apparatus **100** includes a three dimensional printer **120**, a plasma applicator apparatus **130**, and a controller **150**. Specific to this example, the three dimensional printer **120** includes a printing head nozzle **122**, a part carrier **124**, and a supporting structure such as a Cartesian gantry (not shown), a delta-style structure or a robotic arm (not shown) that supports the printing head nozzle **122**. As with the example shown in FIG. **1**, the print head nozzle **122** includes a first end or nozzle tip **122**A, a second end or feed end **122**B, and a feedstock bore **122**C. The print head nozzle **122** is vertically disposed in a housing (not shown).

A three dimensional part **126** is initiated and built upon the part carrier **124** as a polymer filament feedstock **128** and a fiber feedstock **129** combine as they each pass through the print head nozzle **122** and are deposited on the part carrier **124** or a previous layer **131** of the three dimensional part **126**. One of or both of the print head nozzle **122** and the part carrier **124** are capable of movement in the x, y, and z directions, or a combination of these directions composing circular or curved patters, for depositing the heated filament **128** and the fiber feedstock **129** onto the previous layer **131** of the three dimensional part **126**.

The plasma applicator apparatus **130** includes a plasma field applicator **132** and the part carrier **124**. More particularly, the plasma field applicator **132** includes a high voltage electrode **134** encapsulated by a dielectric insulator **136**. The part carrier **124** grounds the three dimensional part **126** to complete a conduction pathway that includes the plasma field applicator **132**, an air gap **138** between the plasma field applicator **132** and the three dimensional part **126**, the grounded three dimensional part **126**, and the part carrier **124**. The print head nozzle **122** is also grounded. As layers of the three dimensional part **126** are fully or at least partially completed, the plasma field applicator **132** moves over the three dimensional part **126** or moves in sufficiently close proximity to the three dimensional part **126** placing the three dimensional part **126** under or incident within a plasma field **140** created by the plasma field applicator **132**. The plasma field **140** completes the conduction pathway to directly couple the high voltage electrode **134** with the three dimensional part **126**. An electromagnetic field and induced current pathway **42**, as shown in FIG. **1**, is produced by the plasma field applicator **132**. The plasma field **140** conductively couples the high voltage electrode **134** to the three dimensional part **126** creating the electromagnetic field and induced current pathway **42**, as shown in FIG. **1**, emanating from the face of the plasma field applicator **132** traveling to the nozzle tip **122**A of the print head nozzle **122**.

Referring now to FIG. **3**, another example of a three dimensional printing apparatus **200** is illustrated and will now be described. The three dimensional printing apparatus **200** includes a three dimensional printer **220**, a plasma applicator apparatus **230**, and a controller **250**. Specific to this example, the three dimensional printer **220** includes a print head nozzle **222**, a part carrier **224**, and a supporting structure such as a Cartesian gantry (not shown), a delta-style structure or a robotic arm (not shown) that supports the print head nozzle **222**. The print head nozzle **222** is a screw-type print head nozzle **222** using a powdered or bulk feed material and includes a first end or nozzle tip **222**A, a second end or feed end **222**B, and an extrusion bore **222**C. The print head nozzle **222** is vertically disposed in a housing (not shown).

A three dimensional part **226** is initiated and built upon the part carrier **224** as a polymer pellet feedstock **228** is fed through the print head nozzle **222** using a extrusion feeder screw **229** and deposited on the part carrier **224** or a previous layer **231** of the three dimensional part **226**. One of or both of the print head **222** and the part carrier **224** are capable of movement in the x, y, and z directions, or a combination of these directions composing circular or curved patters, for depositing the heated filament onto the previous layers of the three dimensional part **226**.

The plasma applicator apparatus **230** includes a plasma field applicator **232** and the part carrier **224**. More particularly, the plasma field applicator **232** includes a high voltage electrode **234** encapsulated by a dielectric insulator **236**. The part carrier **224** grounds the three dimensional part **226** to complete a conduction pathway that includes the plasma field applicator **232**, an air gap **238** between the plasma field applicator **232** and the three dimensional part **226**, the grounded three dimensional part **226**, and the part carrier **224**. The print head nozzle **222** is also grounded. As layers of the three dimensional part **226** are fully or at least partially completed, the plasma field applicator **232** moves over the three dimensional part **226** or moves in sufficiently close proximity to the three dimensional part **226** placing three dimensional part **226** under or incident within a plasma field **240** created by plasma applicator **232**. The plasma field **240** completes the conduction pathway to directly couple the high voltage electrode **234** with the three dimensional part **226**. An electromagnetic field and induced current pathway **42**, as shown in FIG. **1**, is produced by the plasma field applicator **232**. The plasma field **240** conductively couples the potential high voltage electrode **234** to the three dimensional part **226** creating the electromagnetic field and induced current pathway **42**, as shown in FIG. **1**, emanating from the face of the plasma field applicator **232** traveling to the nozzle tip **222**A of the print head nozzle **222**.

Referring now to FIG. **4**, another example of a three dimensional printing apparatus **300** is illustrated and will now be described. The three dimensional printing apparatus **300** includes a three dimensional printer **320**, a plasma applicator apparatus **330**, and a controller **350**. Specific to this example, the three dimensional printer **320** includes a printing head nozzle **322**, a part carrier **324**, and a supporting structure such as a Cartesian gantry (not shown), a delta-style structure or a robotic arm (not shown) that supports the print head nozzle **322**. The print head nozzle **322** includes a first end or nozzle tip **322**A, a second end or feed end **322**B, and a feedstock bore **322**C. The print head nozzle **322** is vertically disposed in a housing (not shown).

A three dimensional part **326** is initiated and built upon the part carrier **324** as a metal composite rod feed stock **328** is fed through the printing head nozzle **322** causing the metal composite rod feed stock **328** to melt and deposit the melted metal composite on the part carrier **324** or a previous layer **331** of the three dimensional part **326**. One of or both of the print head **322** and the part carrier **324** are capable of movement in the x, y, and z directions, or a combination of these directions composing circular or curved patters, for depositing the heated filament onto the previous layers of the three dimensional part **326**.

The plasma applicator apparatus **330** includes a plasma field applicator **332** and the part carrier **324**. More particularly, the plasma field applicator includes a high voltage electrode **334** encapsulated by a dielectric insulator **336**. The part carrier **324** grounds the three dimensional part **326** to complete a conduction pathway that includes the plasma field applicator **332**, an air gap **338** between the plasma field applicator **332** and the three dimensional part **326**, the grounded three dimensional part **326**, and the part carrier **324**. The print head nozzle **322** is also grounded. As layers of the three dimensional part **326** are fully or at least partially completed, the plasma field applicator **332** moves over the three dimensional part **326** or moves in sufficiently close proximity to the three dimensional part **326** placing three dimensional part **326** under or incident within a plasma field **340** created by the plasma field applicator **332**. The plasma field **340** completes the conduction pathway to directly couple the high voltage electrode **334** with the three dimensional part **326**. An electromagnetic field and induced current pathway **42**, as shown in FIG. **1**, is produced by the plasma field applicator **330**. The plasma field **340** conductively couples the potential high voltage electrode **334** to the three dimensional part **326** creating the electromagnetic field and induced current pathway **42** as shown emanating from the face of the plasma field applicator **332** traveling to the nozzle tip **322**A of the print head nozzle **322**.

Referring now to FIG. **5**, another example of a three dimensional printing apparatus **400** is illustrated and will now be described. The three dimensional printing apparatus **400** includes a powder compaction type three dimensional printer **420**, a plasma applicator apparatus **430**, and a controller **450**. Specific to this example, the three dimensional printer **420** includes a powder compaction roller **422**, a part carrier **424**, and a supporting structure such as a Cartesian gantry (not shown), a delta-style structure or a robotic arm (not shown) that supports the powder compaction roller **422**. A three dimensional part **426** is initiated and built upon the part carrier **424** as powdered feedstock **428** is deposited on the part carrier **424** or a previous layer **431** of the three dimensional part **426**. The powder compaction roller **422** applies pressure to the previously deposited layer of powdered feedstock **428** onto the prior layer **431**. One of or both of the compaction roller **422** and the part carrier **424** are capable of movement in the x, y, and z directions, or a combination of these directions composing circular or curved patters, for depositing the heated filament onto the previous layers of the three dimensional part **426**.

The plasma applicator apparatus **430** includes a plasma field applicator **432** and the part carrier **424**. More particularly, the plasma field applicator **432** includes a high voltage electrode **434** encapsulated by a dielectric insulator **436**. The part carrier **424** grounds the three dimensional part **426** to complete a conduction pathway that includes the plasma field applicator **432**, an air gap **438** between the plasma field applicator **432** and the three dimensional part **426**, the grounded three dimensional part **426**, and the part carrier **424**. As layers of the three dimensional part **426** are fully or at least partially completed, the plasma field applicator **432** moves over the three dimensional part or moves in sufficiently close proximity to the three dimensional part **426** placing three dimensional part **426** under or incident within a plasma field **440** created by the plasma field applicator **432**. The plasma field **440** completes the conduction pathway to directly couple the high voltage electrode **434** with the three dimensional part **426**. An electromagnetic field and induced current pathway **42**, as shown in FIG. **1**, is produced by the plasma field applicator **430**. The plasma field **440** conductively couples the potential high voltage electrode **434** to the three dimensional part **426** creating the electromagnetic field and induced current pathway emanating from the high voltage electrode **434** and traveling to the compaction roller **422** and/or to the grounded part carrier **424**.

Turning now to FIGS. **6-9**, an example of a three dimensional printing head assembly **520** is shown and will now be described. The three dimensional printing head assembly **520** includes a printing head nozzle **522**, a plasma field applicator **532**, and a housing **560**. More particularly, the printing head nozzle **522** includes a first end or tip **524**, a second end or feed end **526**, and a feedstock bore **528**. The printing head nozzle **522** is vertically disposed in the housing **560** having the plasma field applicator **532** disposed on the tip **524** of the printing head nozzle **522** coaxially with the printing head nozzle **522**.

The plasma field applicator **532** includes a high voltage electrode **534** encapsulated by a dielectric insulator **536** and is best viewed in FIG. **9**. The housing **560** includes a number of high voltage wire connectors **562** that provide connectivity between the plasma field applicator **532** and a controller (not shown) or between the printing head nozzle **522** and the ground.

The description of the invention is merely exemplary in nature and variations that do not depart from the spirit of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.

We claim:

1. A three-dimensional printing apparatus for manufacturing a three-dimensional object, the apparatus comprising:

a controller having a signal generator;

a three-dimensional printer having a print head, a part carrier, and a plasma field applicator, the print head including a print head nozzle, and wherein the plasma field applicator is disposed on an end of the print head, the print head nozzle is grounded, the controller is in communication with the print head, part carrier, and plasma field applicator, and the three-dimensional printer builds the three-dimensional object onto the part carrier; and

wherein the signal generator outputs a signal to the plasma field applicator and the plasma field applicator generates an electromagnetic field and induced current pathway incident to the three-dimensional object on the part carrier;

wherein the plasma field applicator comprises a voltage electrode and a dielectric insulator, and the voltage electrode is encapsulated by the dielectric insulator;

wherein the dielectric insulator is a single-piece body comprising a disc with an outer annular surface that faces radially outward in a direction away from the electrode.

2. The three-dimensional printing apparatus of claim **1** wherein the signal to the plasma field applicator comprises a potential electromagnetic signal.

3. The three-dimensional printing apparatus of claim **2** wherein the potential electromagnetic signal comprises an alternating current signal having a frequency between approximately 10 kHz and 100 kHz.

4. The three-dimensional printing apparatus of claim **2** wherein the potential electromagnetic signal comprises one of a continuous wave signal, a square wave signal, a triangle wave signal, a short duration pulse signal, and a rectified signal.

5. The three-dimensional printing apparatus of claim **1** wherein the voltage electrode of the plasma field applicator is connected to the signal generator and the part carrier is grounded.

6. The three-dimensional printing apparatus of claim **5** wherein the plasma field applicator has a disc-like shape.

7. The three-dimensional printing apparatus of claim **1** wherein the print head is a pass through continuous feed stock print head nozzle.

8. The three-dimensional printing apparatus of claim **1** wherein the print head is a screw-type extrusion print head nozzle.

9. The three-dimensional printing apparatus of claim **1** wherein the print head includes a powder compaction roller.

10. A three-dimensional printing apparatus for manufacturing a three-dimensional object, the apparatus comprising:

a controller having a signal generator;

a three-dimensional printer having a print head, a part carrier, and a plasma field applicator, the print head including a print head nozzle, and wherein the plasma field applicator is disposed on an end of the print head, the print head nozzle is grounded, the controller is in communication with the print head, part carrier, and plasma field applicator, the plasma field applicator has a disc-like shape, and the three-dimensional printer builds the three-dimensional object onto the part carrier; and

wherein the signal generator outputs a potential electromagnetic signal to the plasma field applicator and the plasma field applicator generates an electromagnetic field and induced current pathway incident to the three-dimensional object on the part carrier;

wherein the plasma field applicator comprises a voltage electrode and a dielectric insulator, and the voltage electrode is encapsulated by the dielectric insulator;

wherein the dielectric insulator is a single-piece body comprising a disc with an outer annular surface that faces radially outward in a direction away from the electrode.

11. The three-dimensional printing apparatus of claim **10** wherein the potential electromagnetic signal comprises an alternating current signal having a frequency between approximately 10 kHz and 100 kHz.

12. The three-dimensional printing apparatus of claim **10** wherein the potential electromagnetic signal comprises one of a continuous wave signal, a square wave signal, a triangle wave signal, a short duration pulse signal, and a rectified signal.

13. The three-dimensional printing apparatus of claim **10** wherein the voltage electrode of the plasma field applicator is connected to the signal generator and the part carrier is grounded.

14. The three-dimensional printing apparatus of claim **13** wherein the print head is a pass through continuous feed stock print head nozzle or a screw-type extrusion print head nozzle.

15. The three-dimensional printing apparatus of claim **13** wherein the print head includes a powder compaction roller.

16. A three-dimensional printing apparatus for manufacturing a three-dimensional object, the apparatus comprising:

a controller having a signal generator;

a three-dimensional printer having a print head, a part carrier, and a plasma field applicator, and wherein the plasma field applicator is disposed on an end of the print head, the controller is in communication with the print head, part carrier, and plasma field applicator, the plasma field applicator has a disc-like shape, the three-dimensional printer builds the three-dimensional object onto the part carrier, and the print head includes a print head nozzle that is a pass through continuous feed stock print head nozzle or a screw-type extrusion print head nozzle; and

wherein the signal generator outputs a potential electromagnetic signal having a frequency between approximately 10 kHz and 100 kHz to the plasma field applicator and the plasma field applicator generates an electromagnetic field and induced current pathway incident to the three-dimensional object on the part carrier;

wherein the plasma field applicator comprises a voltage electrode and a dielectric insulator, and the voltage electrode is encapsulated by the dielectric insulator;

wherein the dielectric insulator is a single-piece body comprising a disk with an outer annular surface that faces radially outward in a direction away from the electrode.

17. The three-dimensional printing apparatus of claim **16** wherein the potential electromagnetic signal comprises one of an alternating current signal, a continuous wave signal, a square wave signal, a triangle wave signal, a short duration pulse signal, and a rectified signal.

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